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TITLE: ENHANCED HIGH EFFICIENCY FUEL CELL / TURBINE POWER PLANT

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ENHANCED HIGH EFFICIENCY FUEL CELL / TURBINE POWER PLANT

Background of the Invention

This invention relates to fuel cell systems and, in particular, to integrated fuel cell and gas turbine systems having enhanced efficiency.

A fuel cell is a device which directly converts chemical energy stored in hydrocarbon fuel into electrical energy by means of an electrochemical reaction. Generally, a fuel cell comprises an anode and a cathode separated by an electrolyte, which serves to conduct electrically charged ions.

A fuel cell may be combined with a heat engine such as a turbine generator to produce a high efficiency system, commonly called a hybrid system. In a conventional hybrid system, the fuel cell is typically situated in the position normally occupied by the combustor of the turbine generator so that air compressed by the turbine generator compressor section is heated and then sent to the fuel cell cathode section. In this arrangement, the fuel cell is operated at a high pressure, which substantially increases the cost of the power plant hardware and inhibits the use of internal reforming in the fuel cell. This further increases the plant cost and reduces efficiency, and subjects the fuel cell to potentially damaging pressure differentials in the event of plant upset. Furthermore, the fuel cell pressure is coupled with gas turbine pressure, limiting the application to system designs where the gas turbine pressure is nearly matched with the fuel cell pressure.

To overcome these disadvantages, another type of arrangement of a hybrid system has been developed, where a turbine generator is bottomed with a fuel cell so that the heated

air discharged from the gas turbine is delivered to the cathode section of the fuel cell. U.S. patent No. 6,365,290, assigned to the same assignee hereof, discloses such a hybrid fuel cell/gas turbine system, in which waste heat from the fuel cell is used by a heat recovery unit to operate the heat engine cycle, and the system is arranged such that the compressed oxidant gas, heated in the heat recovery unit and by a heat exchanger, is expanded in the expansion cycle of the heat engine. It is then passed through an oxidizer which also receives the anode exhaust, passed through the heat exchanger and the resultant gas delivered to the cathode section of the fuel cell.

The aforesaid system of the '290 patent permits the fuel cell to be a high temperature fuel cell, while achieving a relatively high efficiency. However, the system also requires that the fuel cell size and the gas turbine size be matched in order to produce optimal efficiencies. This limits the usefulness of the system.

It is therefore an object of the present invention to provide an improved hybrid fuel cell/turbine system having greater flexibility in the balance of power between the fuel cell and the turbine.

It is a further object of the present invention to provide a hybrid fuel cell/turbine system which has enhanced efficiency and increased power output.

Summary of the Invention

In accordance with the principles of the present invention, the above and other objectives are realized in a hybrid fuel cell system comprising a fuel cell having an anode section and a cathode section, a heat engine having a compressor cycle compressing oxidant supply gas and an expansion cycle, and a heat recovery unit responsive to exhaust gas from

the cathode section of the fuel cell. The heat recovery unit supplies heat to the compressed oxidant supply gas which is then expanded in the expansion cycle of the heat engine to provide an expanded oxidant supply gas and produce mechanical energy for conversion to electrical energy in a generator. A bypass assembly segments the expanded oxidant supply gas into a first expanded oxidant supply gas portion and a second expanded oxidant supply gas portion, and the first expanded oxidant supply gas portion is used to generate the oxidant supply gas input to the cathode section of the fuel cell and the second expanded oxidant supply gas portion is excluded from the fuel cell.

In the embodiments of the invention to be disclosed hereinafter, the bypass assembly includes a controllable bypass valve having an input port receiving the expanded oxidant supply gas from the expansion cycle of the heat engine and first and second output sections for outputting the first and second expanded oxidant supply gas portions. The first section communicates with a line to the fuel cell and the second section communicates with a bypass line communicating with a line responsive to the cathode exhaust gas, the bypass line forming a part of the bypass assembly. The bypass assembly also includes a control scheme such as a gas flow detector and control for detecting the second expanded oxidant gas portion and for adjusting the bypass valve for controllably apportioning the first and second expanded oxidant gas portions. In this way, the compressor cycle of the heat engine and the fuel cell can be operated at their highest efficiencies.

Embodiments of the invention using a carbonate fuel and a solid oxide fuel cell are disclosed.

Brief Description of the Drawings

The above and other features and aspects of the present invention will become more apparent upon reading the following detailed description in conjunction with the accompanying drawing, in which:

FIG. 1 shows an improved hybrid fuel cell/turbine system using a carbonate fuel cell in accordance with the principles of the present invention; and

FIG. 2 shows an improved hybrid fuel cell/turbine system using a solid oxide fuel cell in accordance with the principles of the present invention.

Detailed Description

FIG. 1 shows a first embodiment of a hybrid fuel cell system 1 in accordance with the principles of the present invention. The system 1 includes a high temperature fuel cell 2 having an anode section 2A and a cathode section 2B. As shown, the high temperature fuel cell 2 is an internally reforming or a direct carbonate fuel cell. However, an externally reforming carbonate fuel cell can also be employed. The DC output of the fuel cell 2 is fed to a DC to AC converter 5 to provide an AC output 5A.

The hybrid system 1 includes a heat engine 3, shown illustratively as a turbine generator, having a gas compressor section 3A for carrying out a gas compression cycle and a gas decompression or expansion section 3B for carrying out a gas expansion cycle. The heat engine 3 also includes a generator 3C coupled to the heat engine 3 for converting mechanical energy produced in the expansion cycle into electrical energy. Heat engines such as a gas turbine or a Sterling cycle engine may be employed as a typical heat engine.

The hybrid system 1 also comprises a heat recovery unit ("HRU") 4 which receives fuel at near ambient pressure and water from respective fuel and water supplies (not shown). The heat recovery unit 4 also receives heated exhaust gas at approximately 1150 to 1200 degrees Fahrenheit from the cathode section 2B of the fuel cell 2. This heated exhaust gas includes unspent oxidant gas as well as products of combustion, i.e. carbon dioxide and water.

The heat recovery unit 4 is used to heat the water to the point of producing steam and to heat the fuel to a temperature suitable for entry into the fuel cell anode. The heat recovery unit 4 also acts as a heat exchanger for the oxidant gas compressed by the compressor cycle 3A of the heat engine 3, whereby the compressed oxidant gas is heated to a temperature between 900 and 1100 degrees Fahrenheit. The heated compressed oxidant gas is then conveyed to a further heat exchanger 6 for further heating to a high temperature exceeding 1400 degrees Fahrenheit. After being heated in the heat exchanger 6, compressed oxidant gas is passed through the expansion section 3B of the heat engine 3 where it expanded to a low pressure of approximately 15.5 psia, producing mechanical energy for conversion to electrical energy by the generator 3C.

A portion of the expanded gas (output section 9C of valve 9) is fed to an oxidizer 7 which also receives the exhaust gas from the anode section 2A of the fuel cell containing unspent oxidant and products of combustion, i.e. carbon dioxide and water. The output stream from the oxidizer is cooled in the heat exchanger 6 to a temperature suitable for entry into the cathode section 2B of the fuel cell.

In accordance with the invention 1 and as shown in FIG. 1, the hybrid system 1 also comprises a bypass assembly 8 for bypassing a portion of the expanded oxidant gas from the turbine expansion section outlet around the fuel cell 2 to the fuel cell cathode exhaust stream. As an example, the bypass assembly 8 includes a bypass line 8A, a controllable gas flow control valve 9, such as, for example, a three-way valve or a diverter valve, and a gas flow detector and controller 10.

The gas flow control valve has an input port 9A coupled to the output of the heat engine expansion (turbine) section 3B and first and second output sections 9B and 9C. The first output section 9B couples with the bypass line 8A which, in turn, is connected to the line carrying the exhaust gas from the cathode section 2B of the fuel cell 2. The second output section 9C connects to the line feeding the oxidizer 7. By adjusting the valve 9 via the valve actuator assembly 9D (shown as a motor driven actuator) based on the gas flow in the latter line detected by the flow detector 11, the expanded oxidant gas from the expansion cycle 3B of the heat engine 3 can be controllably apportioned to the output sections 9B and 9C. In this way, the amounts of expanded oxidant gas fed to the fuel cell 2 and bypassed around the fuel cell can be adjusted to optimize the efficiency of the system 1.

More particularly, the gas flow control valve 9 can be adjusted so that the amount of the expanded oxidant gas coupled to the output section 9B is sufficient and optimum for the operating condition of the fuel cell 2. In addition, the apportioning of the gas between the output sections 9B and 9C can be adjusted in order to achieve optimal fuel cell temperature distribution and oxygen concentration in the fuel cell 2. Accordingly, the gas flow control

valve 9 and the gas flow detector 11 function to control and optimize the balance of power between the fuel cell 2 and the heat engine 3 during the operation of the hybrid system 1.

As can also be appreciated, use of the bypass assembly 8 allows the heat engine 3 to operate at a higher gas flow than what is required by the fuel cell operation, which, in turn, results in greater recuperation of heat. Therefore, the heat engine 3 is capable of generating more power than it would in the absence of the assembly 8. Such additional power results in higher efficiency and reduced costs of the system 1. Moreover, the bypass assembly 8 eliminates the matching restrictions between the size of the fuel cell 2 and the size of the heat engine 3. Accordingly, the hybrid fuel cell system can employ commercial heat engines capable of operating at higher gas flows than the maximum gas flow allowed by a particular fuel cell.

A system analysis was carried out on the hybrid fuel cell/gas turbine system 1 in accordance with the present invention using a 40 MW power plant, an internally reforming molten carbonate fuel cell and a gas turbine. This system analysis was then compared with the system analysis for a hybrid fuel cell/gas turbine system without a bypass line, as disclosed in the '290 patent. The following projected operating characteristics were determined for these systems:

	Improved Hybrid System of the Invention	Hybrid System of the '290 patent
Oxidizer Gas Flow		
Gas Flow to Turbine (lb/s)	96	80
Gas Flow to Bypass (lb/s)	16	-
Fuel Cell Power		
DC Power (MW)	33.548	33.548
Power Loss (MW)	1.006	1.006

AC Output (MW)	32.542	32.542
Turbine Power		
Turbine Power (MW)	20.968	17.472
Compressor Power Loss (MW)	10.728	8.936
Generator Power Loss (MW)	0.512	0.427
Turbine Power Output (MW)	9.728	8.109
Hybrid System		
Total System Output (MW)	41.966	40.347
Overall LVH Efficiency:	75.1%	72.2%

As shown above, the operation of the hybrid fuel cell/gas turbine system 1 according to the present invention resulted in a 2.9 percent efficiency increase and a 4% increase in power output over the hybrid fuel cell/gas turbine system of the '290 patent. In addition, the hybrid system 1 of the invention was capable of employing a more powerful gas turbine, thus producing a higher gas turbine power output than in the hybrid system of the '290 patent.

FIG. 2 shows a second embodiment of a hybrid fuel cell system 11 in accordance with the principles of the present invention. In this embodiment, the high temperature fuel cell employed is a is a solid oxide fuel cell 12 having an anode section 12A and a cathode section 12B. As shown in FIG. 2, the solid oxide fuel cell 12 is an internally reforming solid oxide fuel cell. However, an externally reforming solid oxide fuel cell can also be employed. The DC output of the fuel cell 12 is fed to a DC to AC converter 21 to provide an AC output 21A.

The solid oxide hybrid system 11 comprises a heat engine 13, shown illustratively as a turbine generator, having a gas compressor section 13A for carrying out a gas compression cycle and a gas expansion section 13B for carrying out a gas expansion cycle. The heat engine 13 also includes a generator 13C coupled to the gas expansion section 13B for converting mechanical energy produced in the gas expansion cycle into electrical energy.

The solid oxide hybrid system 11 also comprises a heat recovery unit ("HRU") 14 and an oxidizer 17. The oxidizer 17 receives heated exhaust gas from the cathode section 12B of the fuel cell 12 containing unspent oxidant gas, and a portion of the exhaust gas from the anode section 12A of the fuel cell 12 containing unspent fuel and reaction byproducts, i.e., carbon dioxide and water. The oxidizer output stream is fed to the heat recovery unit 14.

The heat recovery unit 14 acts as a heat exchanger for the oxidant gas compressed by the compressor cycle 13A of the heat engine 13, whereby the compressed oxidant gas is heated to an elevated temperature in excess of 1400 degrees Fahrenheit by the oxidizer output. The heated compressed oxidant gas is then passed through the expansion section 13B of the heat engine 13 where it is expanded to a low pressure of approximately 15.5 psia, producing mechanical energy for conversion to electrical energy by the generator 13C. A portion of the expanded gas (output section 9C of the valve 9) is then fed to the cathode 12B of the solid oxide fuel cell 12.

In accordance with the second embodiment of the invention and as shown in FIG. 2, the hybrid solid oxide fuel cell system also comprises a bypass assembly 18 for bypassing a portion of the expanded oxidant gas from the turbine expansion section outlet around the

fuel cell 12 and the oxidizer 17 to the oxidizer exhaust stream. As an example, the bypass assembly comprises a bypass line 18A, a controllable gas flow control valve 19, such as, for example, a three-way valve or a diverter valve, and a gas flow detector and controller 20.

The gas flow control valve 19 comprises an input port 19A, and output ports 19B and 19C and a valve actuator assembly motor 19D (shown as a motor driven actuator). The input port 19A is coupled to the output of the heat engine expansion section 13B. The first output section 19B is coupled with the bypass line 18A, which, in turn, is connected to the line carrying the oxidizer exhaust gas from the oxidizer 17 to the heat recovery unit 14. Alternately, the bypass line may be connected to the exhaust from the cathode 12B instead of the exhaust from the oxidizer 17. The second output section 19C connects to the line feeding the cathode section 12B of the solid oxide fuel cell 12. By adjusting the gas flow control valve 19 via the motor 19D based on the gas flow in the latter line detected by the gas flow detector 20, the expanded oxidant gas from the expansion cycle 13B of the heat engine 13 can be controllably apportioned to the output sections 19B and 19C. In this way, as in the embodiment in FIG. 1, the amounts of expanded oxidant gas fed to the solid oxide fuel cell 12 and bypassed around the fuel cell 12 can be adjusted to optimize the efficiency of the system 11 and to control and optimize the balance of power between the fuel cell 12 and the heat engine 13 during the system's operation.

In all cases it is understood that the above-described arrangements are merely illustrative of the many possible specific embodiments which represent applications of the present invention. Numerous and varied other arrangements can be readily devised in accordance with the principles of the present invention without departing from the spirit and

scope of the present invention. Thus, for example, the principles of the invention can be adapted to other high temperature fuel cells, such as, for example, proton conducting fuel cells. Additionally, the principles of the invention apply to both atmospheric as well as high-pressure fuel cells. In the latter cases, the expansion section of the heat engine expands the oxidant gas to the fuel cell operating pressure.